PROGRAM OF SOLAR OBSERVATIONS AND FLARE WARNING AT CATANIA ASTROPHYSICAL OBSERVATORY

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ABSTRACT

Solar observations at Catania Astrophysical Observatory (OACt), carried out in the optical range, are aimed, besides the systematic patrol, also to a continuous monitoring of both active region evolution and transient phenomena, like flares and active prominences. In this paper we present the results obtained from a statistical analysis consisting in comparing data on M and X flares obtained by GOES-8 satellite in the soft X-ray range, with sunspot-groups data obtained at OACt and by NOAA reports. Moreover, we present the results (limited to the period May - November 2001) obtained during a Flare Warning Campaign carried out at OACt and aimed to single out those flare precursors which may be observed at optical wavelengths.

Key words: Solar Observations; Space Weather.

1. INTRODUCTION

It is a well-known fact that coronal mass ejections, responsible for effects on the Earth magnetic field and ionosphere, are always associated with very energetic flares, but it is not yet possible to surely forecast whether and when an active region is going to give rise to a CME (Pick et al., 1999).
In recent years great progress in the comprehension of the flare phenomenon has been achieved, thanks to coordinated observations from Earth and space: ground-based observations give us the opportunity to follow the event in the chromosphere (and, in case of more energetic events, in the photosphere), while observations from space in X and EUV ranges allow us to investigate flare behaviour at coronal and transition region levels. Nevertheless, there are still several unclear points, such as the role played by the emergence of subphotospheric magnetic fields in pre-existing active regions, or the details of the reconnection process, invoked by many authors as the main mechanism responsible for flare occurrence (Priest, 2001). Therefore, further coordinated ground-based and space observations, performed with higher spatial, temporal and spectral resolution, are necessary to clarify the details of phenomena occurring in active regions before and during flares. In this context, we have focussed our attention on the possibility of singling out the most favourable conditions an active region must develop in order to be flare-productive. We have therefore used data on sunspot-groups (Catania Astrophysical Observatory and NOAA reports), and data on very energetic flares, obtained in the soft X-ray range by GOES 8, in order to define a grid of parameters which may better identify whether and when an active region is going to produce a flare and, ultimately, a coronal mass ejection.

2. SOLAR OBSERVATIONS AT CATANIA ASTROPHYSICAL OBSERVATORY

Solar observations at Catania Astrophysical Observatory (OACt) are carried out by means of an equatorial spar, which includes three instruments:

- Cook refractor, used to make daily drawings of sunspot-groups from visual observation;
- 150-mm refractor (230 cm focal length) with an H_α Lyot-filter (bandwidth of 0.25 or 0.50 $\AA$, tunable filter range $\pm 1\AA$) and a 1360 × 1200 Astromed TE4 CCD array (in patrol full disk mode the camera can take images every 40 sec), with a dynamical range of 16 bits;
- 150-mm refractor feeding an H_α Halle-filter for limb observations.

The program carried out by means of these instruments includes: daily drawings of sunspots and pores by projection of the Sun image; digital image acquisition (every 15 minutes) in the H_α line centre and wings, besides monitoring of transient phenomena.
As far as sunspot-groups are concerned, we determine the following parameters : heliographic coordinates of the group mass center, number of sunspots in

Table 1. Type of penumbra in the largest spot

Type	Penumbra
0	No penumbra (pores)
1	Rudimentary
2	Small symmetric (diam. $< 2^o.5$)
3	Small asymmetric (diam. $< 2^o.5$)
4	Large symmetric (diam. $> 2^o.5$)
5	Large asymmetric (diam. $> 2^o.5$)

the group, number of pores in the group, corrected area in millionth of the solar hemisphere, type according to Zurich classification, type of penumbra in the largest spot (see Table 1), relative importance of the Leading (L) or Following (F) spot and sunspot population density (SPD) (see Table 2).

3. NUMBER OF M OR X FLARES AS A FUNCTION OF DIFFERENT ACTIVE REGION PARAMETERS

We have carried out a statistical analysis in order to identify a possible correlation between the occurrence of very energetic flares (class M or X in the soft X-ray range) and some parameters which characterize sunspot-groups. In the following graphs we show the results obtained from the comparison of X-ray data (GOES 8) with sunspot-group data, concerning M and X flares, occurred during the period 1996-2001. Each graph shows the M and X flare number (NMX) as a function of a different sunspot-group parameter : Fig. 1 (a): NMX vs. number of sunspots in the group (we have considered only sunspot-groups having an heliocentric angle $\leq 70^o$) (OACt); Fig. 1 (b) NMX vs. number of pores in the group (OACt); Fig. 1 (c): NMX vs. sunspot-group area in millionths of the solar hemisphere (OACt); Fig. 1 (d): NMX vs. Sunspot-group longitudinal extension (NOAA); Fig. 2 (a): NMX vs. sunspot-group Zurich class (OACt); Fig. 2 (b): NMX vs. sunspot-group magnetic configuration (NOAA); Fig. 2 (c): NMX vs. type of penumbra in the largest sunspot of the group (OACt)(see Table 1); Fig. 2 (d): NMX vs. relative importance of the L or F spot and sunspot population density (SPD)(OACt)(see Table 2).

The results of our statistical analysis indicate that M or X flares occur more frequently in the following conditions :

- Number of sunspots in the group lower or equal to 10;
- Number of pores in the group lower or equal to 5;
- sunspot-group characterized by an area in the 300 $\div$ 600 millionths of the solar hemisphere range;
- Sunspot-group longitudinal extension in the 6 - 20 degree range;
- D, E, F Zurich class;
- Magnetic configuration β (sunspot group having both positive and negative magnetic polarities, with a simple and distinct division between the polarities); $\beta\gamma$ (sunspot group that is bipolar but sufficiently complex that no single, continuous line can be drawn between spots of opposite polarities); $\beta\gamma\delta$ (sunspot group of beta-gamma magnetic classification but containing one (or more) delta spot(s)).
- sunspot-group showing a type of penumbra in the largest spot characterized by a large asymmetry and a diameter greater than 2,5 degrees;
- Largest leading spot and intermediate sunspot population density.

Table 2. Relative importance of the Leading (L) or Following (F) spot and sunspot population density (SPD)

1	L spot largest; SPD open
2	F spot largest; SPD open
3	L and F spots same size; SPD open
4	L spot largest; SPD intermediate;
5	F spot largest; SPD intermediate;
6	L and F spots same size; SPD intermediate;
7	L spot largest; SPD compact;
8	F spot largest; SPD compact;
9	L and F spots same size; SPD compact;
X	Unipolar spots

4. FLARE PRECURSORS AND FLARE WARNING CAMPAIGN AT OACT

Flares occur in active regions which show a complex magnetic configuration and rapid changes in their structure. Observations have shown that there are some events that can be considered specific flare precursors (sheared magnetic fields, emerging magnetic flux, sigmoid shape of coronal arcades,... etc.) (Martin, 1980, Zuccarello et al., 2002). In particular, in the optical range, the following phenomena are considered flare precursors:

- Filament formation and/or activation;
- Emersion of new pores and/or spots inside an active region;

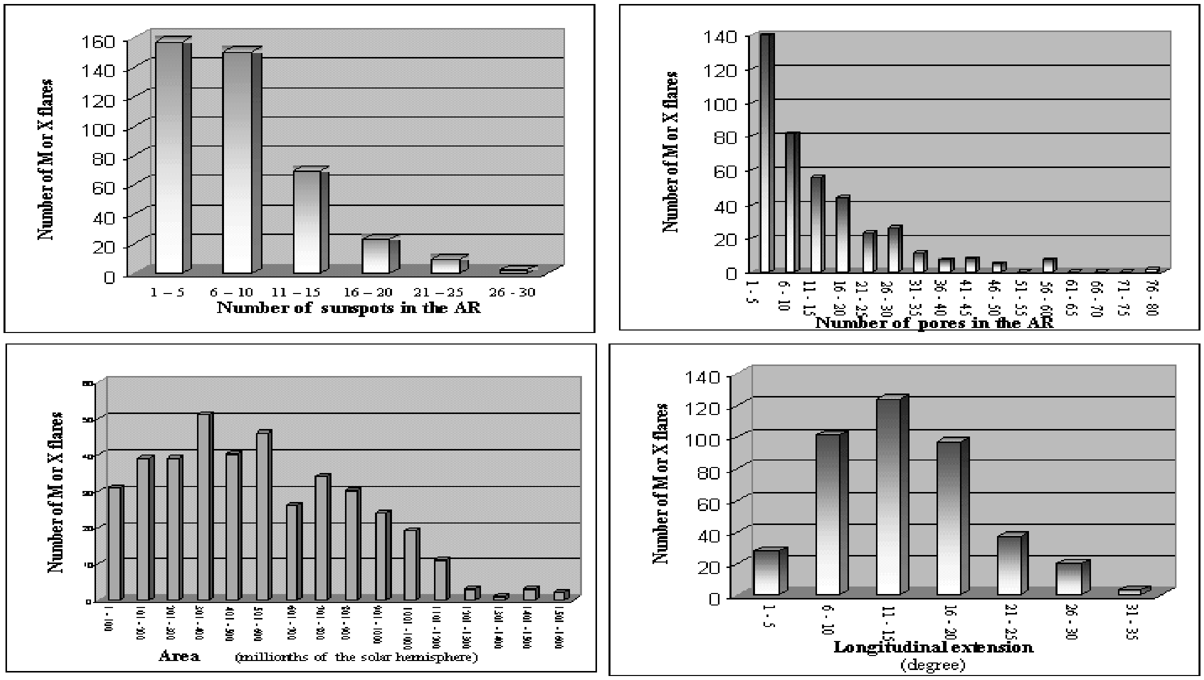

Figure 1. Number of M and X flares during the period 1996-2001 as a function of : a) Number of Sunspots in the group; b) Number of pores in the group; c) Sunspot-group area in millionths of the solar hemisphere; d) Sunspot-group longitudinal extension.

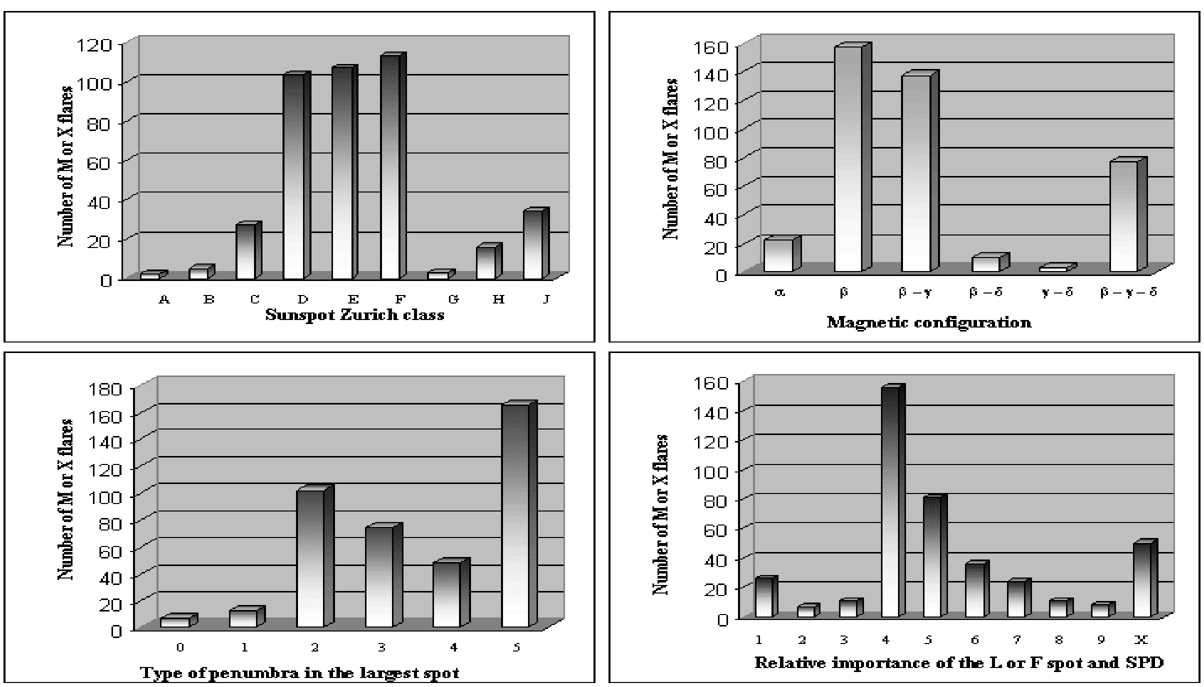

Figure 2. Number of M and X flares during the period 1996-2001 as a function of : a) Sunspots Zurich class; b) Sunspot-group magnetic configuration c) Type of penumbra in the largest spot; d) Relative importance of the L and F spot and SPD.

- Emersion of adjacent active regions;
- Changes in active region configuration (development or decay of spots);
- Motion of spots (development of velocity patterns);
- Changes in fibril orientation;
- Increase in brightness in WL and/or H_α inside the active region;
- Previous occurrence of flares and subflares inside the active region.

Since more than one year, at OACt, it has been activated an observational program of Flare Warning, aimed at monitoring those precursors which may be observed at optical wavelengths. The Flare Warning Program consists in a careful analysis of the characteristics, at optical wavelengths, of each active region present on the disk, and in a comparison with other data taken from space at other wavelengths (EUV, X) and with magnetograms (Big Bear Observatory). When one (or more) active region, which may give rise to a flare, is identified, a Flare Warning message is sent to researchers involved in solar observations. Moreover, the active region is monitored until the flare occurs, when the image acquisition is performed with a higher time resolution. Fig. 3 shows the results of the OACt Flare Warning Campaign concerning the period May - November 2001: Fig. 3 (a) shows that 27 % of Flare Warning (FW) was successfully confirmed by observations, 30 % of FW was confirmed but occurred later than what forecasted; 18 % of FW could not be confirmed because there was not sure flare identification and 25 % of FW was without success. Fig. 3 (b) shows the relative percentages concerning the precursors which have been considered to send the Flare Warning : we can see that the highest percentage (57 %) concerns Changes in the Active Region Configuration.

5. CONCLUSIONS

We have presented the results obtained from a statistical analysis which has allowed us to determine a possible identikit of the sunspot group which may give rise to flares: it should have a number of sunspots ≤ 10, a number of pores ≤ 5, an area between 300 and 600 millionths of the solar hemisphere, a longitudinal extension in the $6 \div 20$ degrees range; it should be of type D or E or F and of magnetic configuration β or $\beta\gamma$ or $\beta\gamma\delta$; the largest spot should have a penumbra characterized by a large asymmetry and the leading spot should be the largest.
Moreover, we have presented the results obtained during the Flare Warning Campaign carried out at Catania Astrophysical Observatory, which may be summarized in the following main points :

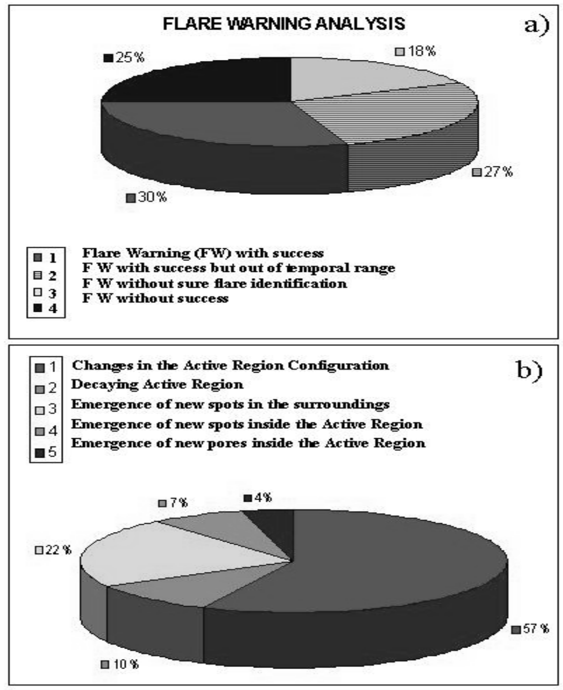

Figure 3. a) Relative percentages of Flare Warnings (FW) done at OACt during the period May - November 2001; b) Relative percentages of precursors used to forecast with success flare occurrence.

- during 7 months of Campaign, 57 % of Flare Warning was successful, 18 % was not confirmed because it was not possible to locate the flare, while 25 % was not correct;
- the most reliable parameter to identify if and when an AR may be flare-productive is related to changes in its configuration.

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